TITLE:

Method for producing a micromachined layered device

TECHNICAL FIELD:

The invention relates to a method for producing a micromachined layered device comprising a membrane layer and a first layer on one side of the membrane layer and a second layer on the opposite side of the membrane layer.

BACKGROUND:

Batch fabrication of very small devices, such as electronics, sensors, and actuators, can be based on wafer handling systems, where the wafer functions as a substrate on to which the device is built during the production steps. The production of such devices is mostly done using a stacking method. The device is built by stacking layer on layer. Each layer can be of a different material, have a different thickness, and can be continuous over the device or laterally confined. The lateral shape of the layer can be defined by including a patterning step based on standard photolithography and microfabrication technologies. Common microfabrication processing steps are for instance ion diffusion, oxidation, deposition of material using e.g. spincoating, physical and chemical deposition methods, removal of materials using e.g. wet and dry etching methods. For an overview of such methods it is referred to G.T.A. Kovacs, K. Petersen, and M. Albin, "Silicon micromachining; Sensors to systems", Analytical chemistry, 1996, 68, p. 407A-412A. In the last step the device can be removed from the substrate. Common methods are dicing and sacrificial layer. A method called "differential

adhesion" is also used.

In dicing, the device, such as integrated circuits (computer chips) that has been built on a silicon wafer, is subsequently cut out using a saw. In this case the substrate becomes a part of the product. This can be a drawback, since the properties suitable for a material to hold a device during process not necessarily go together with the properties required for the final device.

The sacrificial layer method uses an intermediate, sacrificial layer between the substrate and device. The device is built up onto the sacrificial layer. The device is then released from the substrate by removing the sacrificial layer, e.g. by dissolving the layer using an appropriate etchant or solvent. These etchants or solvents can damage the layers of the device. Also, the removal process can take hours for large area devices.

The differential adhesion method is based on the poor adhesion between the top layer of the substrate and the bottom layer of the device. The device is built up using the above mentioned microfabrication steps. As a last step in the production the device is removed from the substrate, by "peeling" it loose. The technique of differential adhesion is described in US 6 103 399.

All of the above production methods however have the disadvantage that these processes are bottom up processes. Only one side is available for processing. Layers are added on top of each other on one side of the device. This means that sensible materials that are added on the bottom side of the devices might be damaged by chemicals during the process. Due to the device design, these layers cannot be added at a later stage in the process, as this means that they will be on the topside of the device. Inversion

of the process steps, i.e. starting with the "top layers" on the substrate is not always possible either. Which, for instance, is the case for processes such as electroplating and electropolymerisation where an electrically conducting seed layer is needed. The device can only be built as substrate/seed layer/electoplated layer and not vice versa.

SUMMARY OF THE INVENTION:

It is therefore an object of the invention to solve the above-described problems.

The problems are solved by the method according to the invention which method comprises the following steps:

a) a membrane layer is applied on a substrate;
b) a window in the substrate is opened so as to free the membrane layer in order to enable the adding of layers from both sides of the membrane layer while the substrate is made into a frame that supports the membrane layer during the processing;
c) at least one layer is added on each side of the membrane either simultaneously or on one side at a time;
d) the device is cut out and removed from the substrate frame.

By the word membrane is meant a thin film of one or more layers of material that sometime during the process is hanging freely between the substrate parts and is being accessible for processing from both sides.

By the expression layered devices is meant not only products consisting of several layers of thin film but also devices comprising other non continuous components than thin films, such as laterally patterned structures.

The method according to the invention makes both sides of device accessible for processing. In this way a more free choice of processing can take place. Material layers that are sensible to chemicals used in the process can be deposited at a later stage.

A further advantage of the method according to the invention is that the invention makes it possible to cut out the device without further processing, e.g. etchants.

Another advantage of the method according to the present invention is that the substrate does not form part of the final device. According to the method the device is cut out of the supporting frame. This is an advantage over prior art, since a device comprising the substrate when in use would be so thick that the device possibly would not work.

Yet another advantage of the method according to the present invention is that the method is suitable for batch fabrication of fragile devices.

Different methods can be used for performing step b) of the method including any of the following methods: laser ablation, wet chemical etching, dissolving, and dry etching including reactive ion etching and sputter etching.

Different methods can be used for performing step d) of the method including any of the following methods: wet chemical etching, dry etching including reactive ion etching and sputter etching, dicing/sawing, cutting with scissors or a knife, laser ablation, or punching.

Step d) may be divided into two steps, where the device is partially cut out in a first step, then activated,

followed by a step where the device is completely cut out from the substrate. Step d) may also be a one step action, after which the device is being activated in a following step e)after the cutting out of the device.

The method can comprise further steps in addition to step a) to d). For instance, a patterning step to alter the lateral dimensions of an added layer, using for instance photolithography or soft lithography.

The substrate may be of a polymeric material, a semiconductor material, e.g. silicon or a metal,. including alloys, such as titanium, stainless steel. Other materials such as glass are also suitable for the substrate layer.

The device layers, i.e. all/any of the layers of the final device, both the membrane layer and the layers added thereafter, may be made of different materials chosen for the purpose of use. For instance, can the device layers be made of layers of metals, metal oxides, or an alloy of metals, including gold, platinum, titanium, stainless steel, aluminium oxides, and a nickel-titanium alloy. Also ceramics, such as hydroxyapatite can be used as a device layer. Other suitable materials for the device layers are conducting polymers, including pyrrole, aniline, thiophene, para-phenylene, vinylene, and phenylene polymers and copolymers thereof, including substituted forms of the different monomers.

Also polymers such as polyimide, polyamide, polyurethane, poly-(tetrafluorethylene), poly-(dimethylsiloxan) (silicon rubber), poly(methylmethacrylate), polyesters, poly(vinyl chloride), and polyethylene, including copolymers and substituted forms of the different monomer

thereof, epoxies, and resins are suitable as device layers.

The invention also relates to a device produced by the above method wherein the device is a microactuator. This means that it is an actuator that has a lateral dimension in the micrometre to centimetre scale and a thickness in the nanometre to millimetre scale.

Preferably, but not necessarily, the methods steps a) to d) are performed in alphabetical order.

According to an embodiment of the invention the membrane layer of the device is deposited on the substrate. Hereafter, the substrate is selectively removed, e.g. by wet chemically etching, under the membrane layer over an area that at least is slightly larger than the final device size. Now, the membrane is freely hanging in the substrate support frame and can be accessed from both sides for additional processing, such as adding one or more layers on either side or both sides. In the last step the device is removed from the frame.

DESCRIPTION OF THE FIGURES:

Figure 1 schematically shows the production steps according to one embodiment of the invention.

Figure 2 shows a device after that it is removed from the substrate and the device in an activated state.

Figure 3 schematically shows the production steps according to a second embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION:

Figure 1 discloses one embodiment of the invention. In figure 1 the production steps are schematically shown. As an example, the production method of an electro-active polymer actuator is shown. However, the invention is not limited to the fabrication of such devices.

As a substrate 1, a thick sheet of titanium is used. The substrate may be of different configurations, such as wafers, pieces, foils, and discs and different materials including metals, semiconductors, plastics, and glass. The substrate may be made in other configurations also, provided that the parameters for enabling are fulfilled. For instance that there is a plane area on the substrate for adding layers. The substrate 1 exhibits a first side A, and a second opposing side B. On side A of the substrate 1, a membrane layer 2 of gold is deposited using for instance thermal evaporation or sputtering (Fig. 1A). Hereafter, a layer of photoresist 3 is deposited in a conventional manner on both sides of the substrate 1 (Fig. 1B). Using standard photolithography, a pattern on side B of the substrate 1 is opened (Fig. 1C). Hereafter, the titanium substrate 1 is wet chemically etched. The substrate 1 is etched until the gold layer 2 is reached. Now a gold membrane has been fabricated, that can be processed on either or both sides (Fig. 1D). In order to make the actuator device, device processing is continued on side B of the substrate 1 while the protective photoresist layer 3 on side A is not removed. This photoresist layer 3 will protect side A during processing of side B. A layer of polypyrrole 4 is deposited on side B of the gold layer 2 using electropolymerisation from an aqueous electrolyte containing pyrrole monomers and a salt (Fig. 1E).

The protective photoresist layer 3 is removed (Fig. 1F) and a structural polymer layer 5 is deposited on side A, for instance using spin coating (Fig. 1G).

The actuator 6 is now finished and can be cut out from the substrate 1 in its final lateral shape (Fig 1H). This can be done for instance using wet chemical etching, Reactive Ion Etching, sawing, cutting with scissors or a knife, laser ablation, or punching. Fig. 1I shows the finished, cut out device.

Figure 2 shows how the actuator 6 will be activated when it has been cut out and removed from the substrate 1. In Fig. 2A the actuator 6 is in its unactivated, newly produced state. In Fig 2B the actuator has been activated and is in a bent state. This kind of actuator is electrochemically activated. More information about these electrochemical polymer actuators can be found in E. Smela, "Microfabrication of PPy microactuators and other conjugated polymer devices", J. Micromech. Microeng., 1999, 9(1), pp. 1-18.

The process scheme described above is an example of fabricating a device, in this case an electrochemical, polymer actuator. The method is not limited to the process of fabricating a three-layer actuator. Those skilled in the art notice that other combinations are possible. The layers 2, 4, and 5, can each comprise of several layers, materials, or thicknesses. The layers 4 and 5 do not have to be continuous layers but can also comprise of patterned structures e.g. beams or rod shaped elements. The structures can be added, on either or both sides. Figure 3 shows an example of such a device. Here, four materials are used, two being patterned. The steps of fabricating the membrane are not shown, but can be made in a manner corresponding to that shown in Fig. 1A to Fig. 1D,

whereafter the photoresist has been removed. I.e. the structure shown in Fig. 1D but without the photoresist is the starting point in Fig. 3A. After the fabrication of the membrane, patterned structures 7 of a fourth material are deposited on side A of the membrane (Fig. 3A). Hereafter, a second layer 4 is deposited on side B (Fig. 3B), followed by a patterned third layer 5 on side A (Fig. 3C). Finally, the device 8 is cut out of the substrate 1 (Fig. 3D). Fig 3E shows the finished device 8, which can be used outside the substrate.

The addition of materials to the device can be done on one side at the time as shown in Fig. 1 and Fig. 3, but also on both sides simultaneously. Some deposition methods, such as electrochemical deposition on a conducting substrate, require that when only processing one side, the other side is protected in order not to deposit on that side as well. For instance, a layer of photoresist could be used for this purpose as is shown in Fig. 1D and Fig. 1E. Other deposition methods, including spin coating and physical vapour deposition, only cover one side and do not need such a protection layer, as is shown in Fig. 1F through Fig. 1G. The sequence onto which side the materials are added is of no importance to the method, but depends on process parameters such as the materials to be added, the device, and production methods. One could deposit all materials on one side first and finish on the other side, or deposit on either side alternatingly. With alternatingly means that one or several layers are deposited on one side and then on the other side.

In another embodiment of the invention the device, for instance a microactuator is fabricated according to step a through c (Fig.1A through 1G). Hereafter the device is partially cut out followed by further processing. Next, the device is completely cut out and thus removed from the

substrate. Now that the device has been removed from it supporting frame, it can be used as intended, e.g. as a microactuator. An advantage with this method is that several microactuators may be activated in one action.

In the figures the fabrication of one device is shown. The method includes batch fabricating many such devices simultaneously by having many such devices on a single substrate. The devices that are manufactured simultaneously can be both identical and different.